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Impact of Passive Shading and Orientation on the Energy Efficiency of the Building

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Abstract

The article deals with a quick assessment of the architectural envelope of the building from an energy perspective in the design process. The software Grasshopper implemented in Rhino 3D, in combination with the energy simulation add-on Ladybug Tools, is used for evaluating passive energy savings. The first part presents the results of optimizing the orientation of the building and its impact on improving the building's energy efficiency. The second part of the article assesses the impact of passive shading on the building's energy balance.

Keywords: solar gain, energy simulation, sustainability, architecture, passive standard architecture

1 Introduction

The increasing demands for energy efficiency in both existing and new buildings require exploring possible optimizations for savings throughout the entire life cycle of a building, from its initial design through to its realization and subsequent reconstruction or renovation [1]. Current technologies and building materials provide a wide range of solutions to help achieve the desired savings in buildings [2]. However, in many cases, passive architectural and construction elements are overlooked, which, when used correctly, can lead to significant savings without the use of technology or changes in material solutions. This article presents the application of an optimalization-simulation method for the correct design of building orientation and assesses the impact of passive shading on the building's energy efficiency using a model example [3,4]. The aim of the paper is to demonstrate the impact of optimization interventions in the process of designing a building on its future energy efficiency [5-12].

2 Methods

To evaluate the presented results, an optimization-simulation method was used. This method is based on simulation using the Energy+ simulation engine, which operates with an hourly simulation step. As a model example, a reference building of a family house (Figure 1) built in the area of eastern Slovakia in the vicinity of Košice was chosen. Meteorological data for the simulation were sourced from the nearest database (Kosice.AP KI SVK119680), located only 11.9 km from the assessed building site, as shown in (Figure 2). The compositions of the external structures, ground floor, and glazing properties are listed in the (Table 1).

Figure 1: Visualisation of the reference building

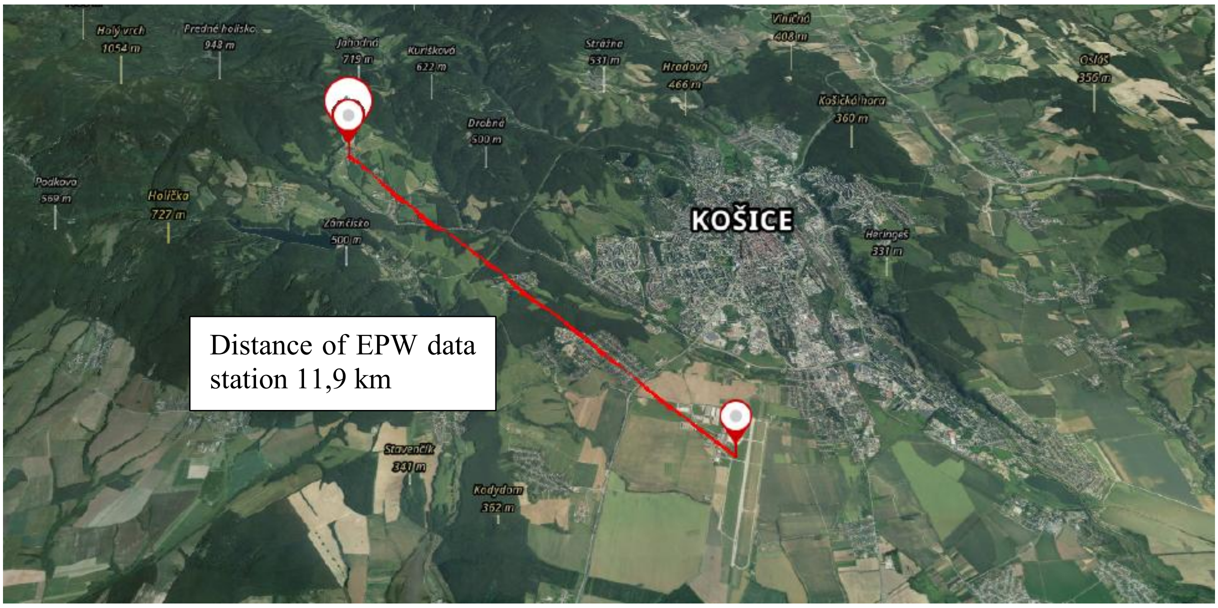

Figure 2: Map showing the distance from the EPW data source station to the building location

2.1 Formatting Input parameter of the heat exchange envelope of the building

Before the simulation, the parameters of the building's thermal envelope were chosen according to the design. The selected parameters of the building's thermal envelope are documented in the following (Table 1).

Table 1: Composition of building envelope constructions

Perimeter wall					
	Thickness (m)	**Thermal conductivity** λ (W.m^{-1}.K^{-1})	**Density** (kg/m^3)	**Specific heat capacity** (J/kg.K)	**R-Thermal resistance layers** (m^2.K/W)
R_{si}					0.13
reinforced concrete	0.2	1.58	2500	1020	0.127
rigid polyurethane	0.2	0.032	35	1500	6.25
PVC waterproofing	0.001	0.35	1470	1470	0.003
R_{se}					0.04
U	0.15 W/(m^2.K)				
roof					
R_{si}					0.1
reinforced concrete	0.2	1.58	2500	1020	0.127
rigid polyurethane	0.3	0.032	35	1500	9.375
PVC waterproofing	0.001	0.35	1470	1470	0.003
R_{se}					0.04
U	0.10 W/(m^2.K)				
floor on ground					
R_{si}					0.17
wooden floor	0.02	0.22	600	2510	0.091
concrete screed	0.05	1.3	2200	1020	0.038
XPS	0.07	0.034	30	2060	2.059
XPS	0.07	0.034	30	2060	2.059
reinforced concrete	0.15	1.58	2500	1020	0.095
soil		1.4			
U	0.15 W/(m^2.K)				
window construction					

		thickness (m)	thermal conductivity λ (W.m^{-1}.K^{-1})	heat transfer coefficient U	Solar factor g/Shgc
glass				0.65	0.6
frame		0.05	3.5		
U	0.15 W/(m^2.K)				

For the heat exchange envelope of the building, parameters have been selected that correspond to the values recommended by the standard. The values recommended by the standard were taken from the standard STN 73 0540-2+Z1+Z2:2019.

Table 2: Volumetric and spatial specifications of the building envelope

Building specification	**p/m**	**a/m^2**	**v/m^3**	**%**
building envelope		394.9		
internal volume			340.9	
circuit	54.2			
flooring		121.5		
window area		29.61		7.5
shape factor			1.16	

The (Table 2) presents the basic surface and volume properties of the building that was the subject of the simulation.

3 Outcomes

Based on a dynamic hourly simulation, results were obtained that serve to optimize the energy requirements of the future building. The results are summarized in two separate subchapters. The first subchapter presents the results of the simulation aimed at achieving the most economical orientation of the building. The second subchapter presents and compares the results of the simulation of heat and cold demand for the same building in two alternatives. In the first alternative, the building is not equipped with passive shading in front of the dominantly glazed facade. In the second alternative, passive shielding is added to the calculation.

3.1 Determining the correct orientation

For the correct determination of the orientation of the future building, 12 alternatives of orientation have been simulated. Each alternative is rotated by 30° compared to the previous one. The simulated solar rotation positions are presented by the following figures (Figure 3).

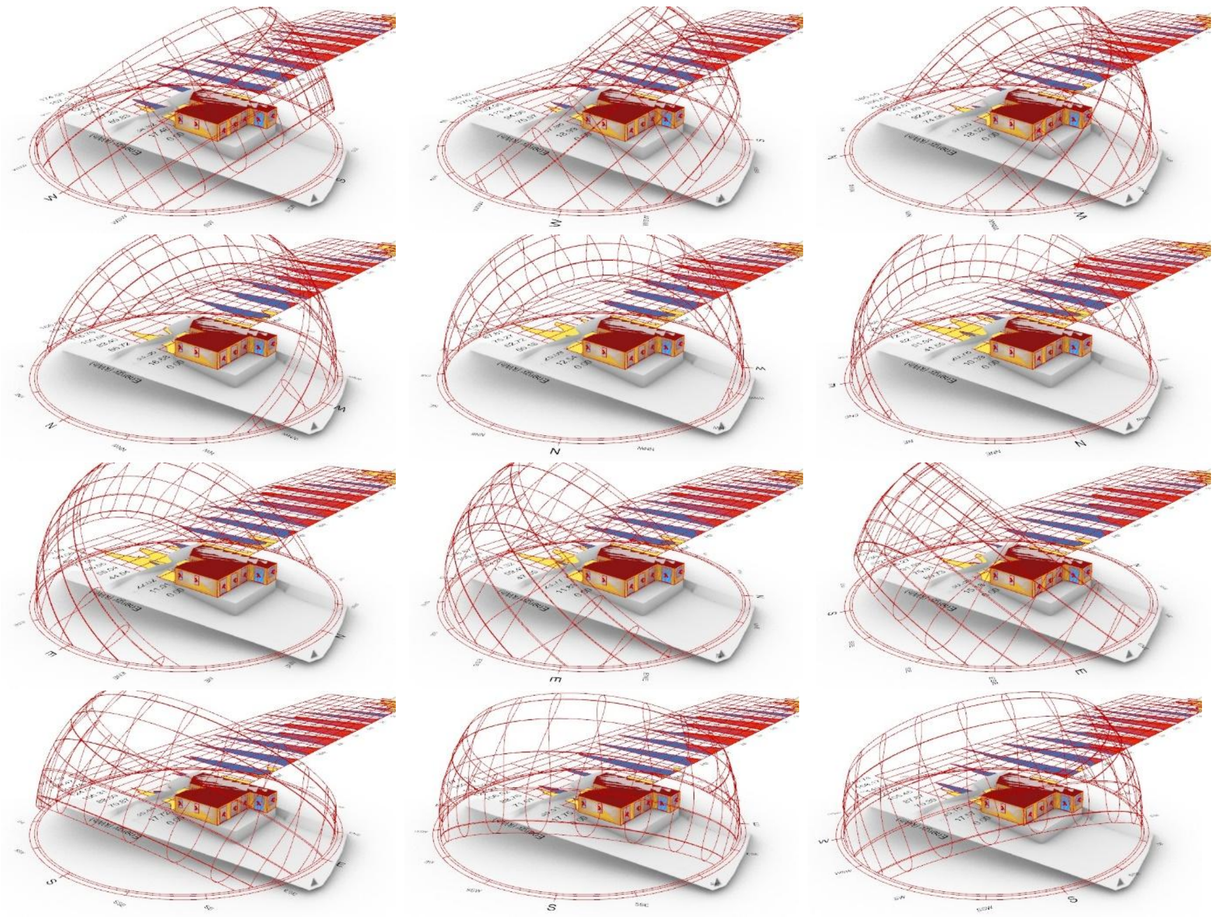

Figure 3: Twelve positions of the north orientation of the sun compass in 30° from 0° to 330° rotation

The (Table 3) presents the simulation results of heating and cooling needs for selected rotations of the building mass relative to the north. The red zone highlights the most economical orientation option with the building mass rotated by 180° in the given area while maintaining the distribution of glazed surfaces relative to the building envelope according to the original design.

Table 3: The record of the simulations of different orientations of the building envelope highlighting the most energy-efficient option

North orientation	**Heating** (kWh)	**Cooling** (kWh)	**Solar gain**	**Sumary** (kWh)
0°	2804.5	4770.9	11517.3	7575.4
30°	3062.2	4760.2	11008.1	7822.3
60°	3458.6	4614.2	10107.9	8072.9
90°	3839.6	4237.7	8969.7	8077.3
120°	4023.0	3770.4	7978.5	7793.4
150°	4024.2	3475.6	7536.8	7499.8
180°	3962.3	3523.0	7750.0	7485.3

210°	3851.5	3873.4	8454.2	7724.9
240°	3658.1	4351.9	9483.5	8010.0
270°	3368.7	4708.1	10522.8	8076.8
300°	3054.6	4930.2	11375.2	7984.8
330°	2819.3	4930.6	11732.8	7749.9

The (Table 3) summarizing the simulation results is graphically illustrated below (Figure 5). From the graph, we can observe how the heat and cooling requirements change depending on the orientation of the building envelope relative to the north. The red rectangle highlights the orientation with the best energy efficiency for the given structure.

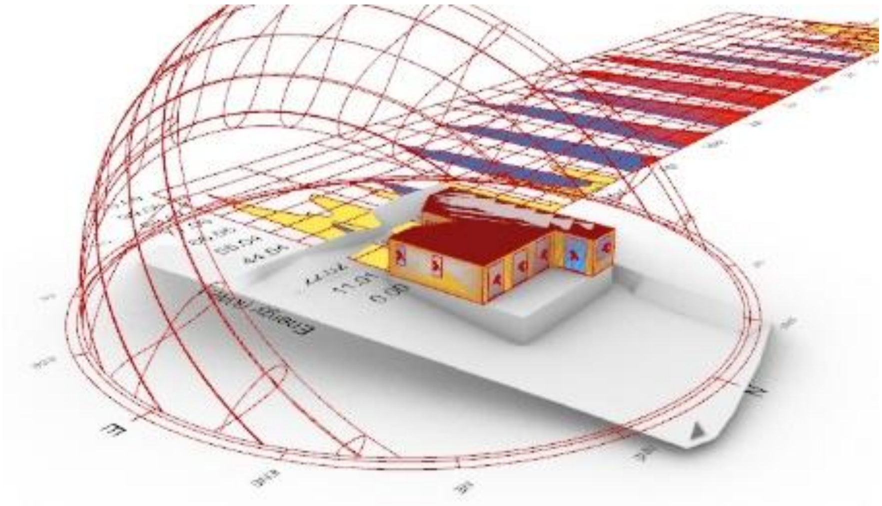

Figure 4: Model represent most economical orientation in180° turn of north direction

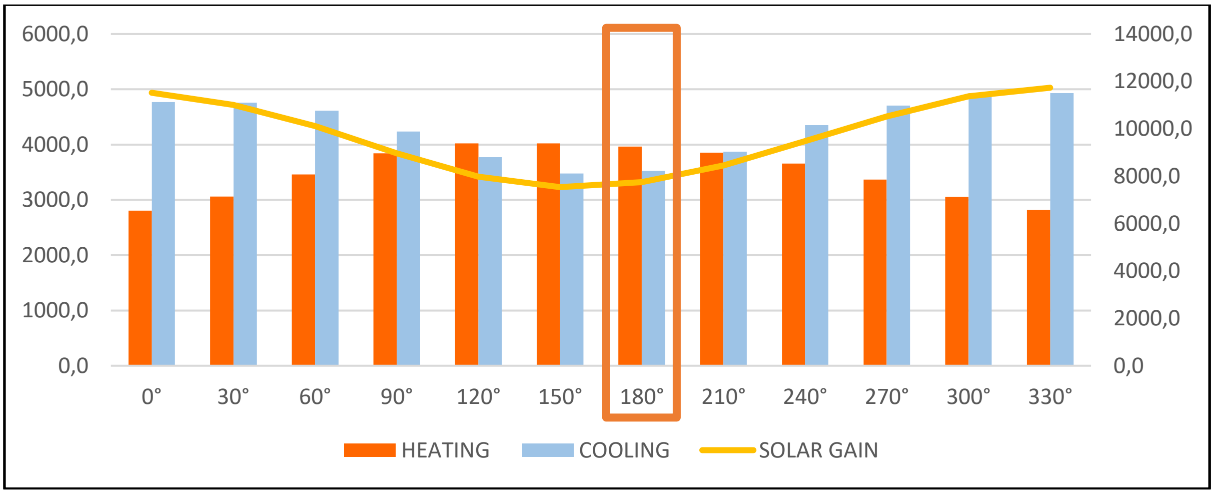

Figure 5: Graphic representation of the development of heat and cold demand depending on the rotation of the building envelope in relation to the cardinal points

Based on the data obtained from the simulation, is able to determine that for a given specific building envelope, an orientation corresponding to a 180° rotation is the most advantageous in terms of energy efficiency.

3.2 The impact of passive shading on energy efficiency

In the next step, the impact of passive shading placed on the facade with the highest proportion of glazed areas was assessed.

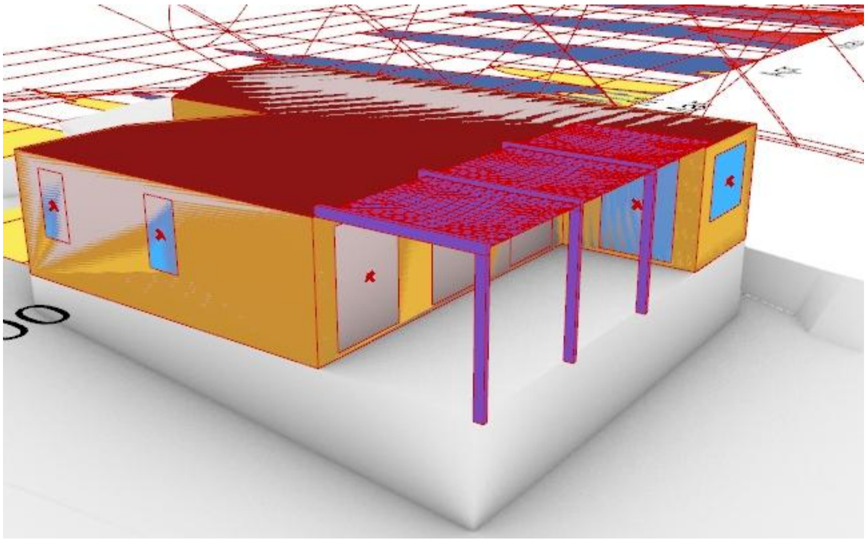

Figure 6: Building envelope mass with added passive shading

Subsequently, a dynamic simulation was carried out considering passive shading in front of the glazed surfaces of the façade. The results of the simulation with added shielding were compared with the results of the simulation without shielding. The results of both simulations are presented by (Table 4).

Table 4: The results of heat and cold demand for the given building envelope when the building is rotated 180° without passive shielding and with passive shielding

North orientation	**Heating** (kWh)	**Cooling** (kWh)	**Solar gain**	**Summary** (kWh)
180° without shading	3962.3	3523.0	7750.0	7485.3
180° with shading	4185.3	2732.2	6136.0	6917.5

As can be seen in (Figure 7), applying passive shading to the façade with the largest glazing ratio significantly reduces the need for cold. The need for heat is slightly increasing in connection with the reduced subsidy of solar gains through glazing. In the total sum of the heat and cold demand for the whole year, this adjustment shows a reduction in the total demand.

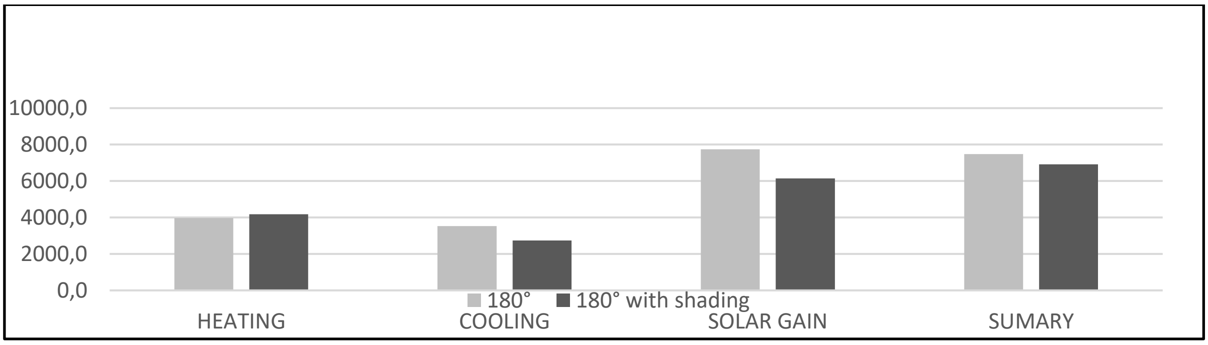

Figure 7: Graph showing the need for heat, cold, solar gains, and the total sum of heat and cold demand for the alternative without and with passive shielding

4 Results

Based on the dynamic simulation, the most suitable orientation of the assessed mass in relation to the cardinal points was determined. This orientation reduces the need for heat and cold compared to the least suitable orientation by 592 kWh. The subsequent involvement of passive shading in front of the façade with the largest glazing area increased the savings from 592 kWh to 1159.8 kWh.

5 Conclusion

Based on the simulation of case studies, the presented article tangibly demonstrates the possibilities of streamlining the architectural design solution in the early stages of design. By incorporating dynamic simulation into the design process, the author is able to make the right decisions towards achieving a more energy-efficient design. For this purpose, in the initial stages of design, it is not necessary to deal with technological solutions, but to properly handle passive elements of architecture, such as the orientation of the mass, the ratio of glazing or passive shading elements. The savings achieved in this way are not negligible, and therefore dynamic simulation should become part of everyday professional practice when designing architectural designs of buildings.

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